AFRL-HE-WP-TR-1998-0136

UNITED STATES AIR FORCE RESEARCH LABORATORY

AN ASSESSMENT OF ALTERNATIVE SYNTHETIC APERTURE RADAR DISPLAY FORMATS: ORIENTATION AND SITUATIONAL AWARENESS

Gilbert G. Kuperman

HUMAN EFFECTIVENESS DIRECTORATE
CREW SYSTEM INTERFACE DIVISION
WRIGHT-PATTERSON AFB, OH 45433-7022

Michael S. Brickner

PAMAM HUMAN FACTORS ENGINEERING LTD.
5 BEN SHALOM STREET
RAMAT HASHARON, 47204, ISRAEL

Itzhak Nadler

HUMAN ENGINEERING BRANCH
ISRAEL AIR FORCE

DECEMBER 1998

INTERIM REPORT FOR THE PERIOD JANUARY 1998 - DECEMBER 1998

Human Effectiveness Directorate
Crew System Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-1998-0136

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

HENDRICK W. RUCK, PhD
Chief, Crew System Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1998	Interim Report; January 1998 to December 1998

4. TITLE AND SUBTITLE
An Assessment of Alternative Synthetic Aperture Radar Display Formats: Orientation and Situational Awareness

5. FUNDING NUMBERS
C: F41624-94-D-6000
P: 62202F
PR: 7184
TA: 10
WU: 44

6. AUTHOR(S)
Gilbert G. Kuperman, Michael S. Brickner, Ph.D.*, Lt Col Itzhak Nadler**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
*PAMAM Human Factors Engineering, Ltd.
5 Ben Shalom Street
Ramat HaSharon, 47204, Israel
**Human Engineering Branch
Israel Air Force

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory, Human Effectiveness Directorate
Crew System Interface Division
Air Force Materiel Command
Wright-Patterson AFB, OH 45433-7022

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study explores the operational utility of fusing synthetic aperture radar (SAR) imagery and digital terrain map (DTM) data. Specifically, the two-dimensional (2-D) display of SAR imagery was compared against a 2 1/2-dimensional (2 1/2-D) display of SAR overlaid on corresponding DTM data. Eight imagery analysts (IAs), assigned to the Israeli Ground Corps Command Imagery Analysis Unit and to the Israel Air Force, and two weapon system officers (WSOs) served as subject matter experts (SMEs). The measures employed in this comparison included both an assessment of operator situational awareness (SA) and of performance in an information extraction task.

Based on the SAR imagery that was used in the experiment, performance measures (accuracy of target location) and SA measures did not yield significant performance differences between the 2-D and the 2 1/2-D displays. The average time required to complete each task was significantly longer for the 2 1/2-D displays.

Based on experience, the SMEs' opinion was that the 2 1/2-D imagery display may be potentially helpful in the performance of various imagery analysis tasks and in enhancing SA.

14. SUBJECT TERMS
Synthetic Aperture Radar, SAR, Digital Terrain Map/Elevation Data, Imagery Exploitation, Situational Awareness, Operator Performance, Human Factors, Information Fusion

15. NUMBER OF PAGES
30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UNLIMITED

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

This page left blank intentionally.

PREFACE

The current study explores the operational utility of fusing synthetic aperture radar (SAR) imagery and digital terrain map (DTM) data. Specifically, the two-dimensional display of SAR imagery was compared against the 2 ½-dimensional display of SAR overlaid on corresponding DTM data.

The study was conducted with the joint participation of the Israel Air Force (IAF) Human Factors Engineering Branch (HFEB) and the Crew Systems Interface Division of the AFRL's Human Effectiveness Directorate (AFRL/HEC). The research took place in Israel during the period of 19 August through 17 September 1998. The USAF participation was performed under Work Unit 71841044, "Advanced Crew Systems for Reconnaissance, Surveillance and Target Acquisition." Mr. Gilbert G. Kuperman (AFRL/HECA) and Lt Col Itzhak Nadler (Chief, IAF HFEB) served both as principal investigators and as the technical project officers for the DEA for their respective countries. This study was carried out with the contractual support of Synergy Integration, Ltd., Tel Aviv, Israel, in the area of image processing, and by PAMAM Human Factors Engineering, Ltd., Ramat HaSharon, Israel, in the areas of test instrument design, data collection, analysis, and documentation.

In any exploration of this type, the true knowledge resides with the subject matter experts of the operational units. The authors are greatly indebted to the young men and women of the Israeli Ground Corps Command and the Israel Air Force, who shared their expertise so willingly with the experimenters in support of this research.

Individual thanks are due to Ms. Ayelet Oettinger (PAMAM), who so professionally supported the data collection and analysis portions of the study and to both Mr. Jacob Silbiger and Mr. Victor Ben-Ezra (Synergy), who prepared the imagery and terrain data for use as stimuli.

Lastly, special thanks must be expressed to Lt Col Danni Zimra, Israeli Ministry of Defense, Directorate of Defense Research and Development (MAFAT), for his assistance in obtaining the SAR imagery employed in this study.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

This page left blank intentionally.

INTRODUCTION

Background

Synthetic aperture radar (SAR) sensors offer two compelling advantages over conventional (electro-optical) sensing technologies: stand-off range and adverse weather capabilities. SAR images can be formed with effectively no loss in resolution out to the limits of the system's stabilization and motion compensation capabilities. SAR sensors can "see" through clouds and through light rain. Further, depending on their coverage mode and data processing limitations, SAR sensors can be capable of high area coverage rates. These attributes make SAR imaging a valuable resource for tactical and theater airborne reconnaissance, surveillance and target acquisition applications.

The air forces of both the United States and of the State of Israel have great interest in exploiting these capabilities. The USAF has operational SAR capabilities in the B-1B, F-15E, J-STARS, and U-2 systems and plans to include SAR as a primary imaging mode in both the Global Hawk and Dark Star families of uninhabited air vehicles. The IAF has operational SAR capabilities in their Phantom 2000 and F-15I multi-role aircraft and has other SAR capabilities in development.

SAR, however, is a non-literal imaging sensor. That is, the imagery produced by a SAR does not resemble a photograph taken of the same scene. The intensity values in the SAR image are proportional to the radar cross sections of the corresponding points in the ground scene (and not to their visible wavelength reflectance). The impulse response function of the SAR (the fundamental determinant of system resolution) includes side lobes. Thus, the return from a point on the ground may include energy contributed by adjacent scatterers. The "shadows" in a SAR image are caused by the active illumination of the scene by the emitting radar (and not by the sun angle). The perspective of a SAR image is that of an observer looking down onto the scene from directly above, while it is being illuminated by the radar from one side (the location of the SAR).

Because of the non-literal nature of the SAR image, operational questions exist regarding how well an imagery analyst (IA) can orient it against a map reference. A fundamental imagery exploitation task is to confirm (or plot) the actual ground coverage of a collected image against a map reference. Several other standard imagery exploitation tasks (e.g., landform analysis, traversability studies) require that the operator interpret the image so as to assess the basic geologic and terrain characteristics, including judgments of the heights of terrain features and the grades of slopes. Further, orientation may require the IA to locate salient terrain features and to match them against their map references. Understanding of the terrain contributes significantly to the establishment and maintenance of situational awareness, affording the context within which other imagery interpretations may be made. The human operator is unique in having the ability to apply

contextual information to the interpretation of complex visual stimuli (such as reconnaissance imagery).

SAR is not the only technology which may support these operational requirements. Digital terrain map (DTM) data, consisting of elevation "posts," equally spaced in latitude and longitude, provide another source of information regarding the heights and slopes of the terrain. DTM data can be viewed in two dimensions (2–D) as elevation contours or as a continuous tone depiction, in which elevation is coded by luminance values or colors. Two–D image displays may be rotated so that north (or any arbitrary direction) is toward the top of the display. Alternatively, DTM data may be displayed in 2 ½–D, in which a 3–D "model" of the terrain, with a shading scheme applied as if it were illuminated by the sun, is projected onto the 2–D display surface. Two and one-half–D DTM displays may be rotated in both azimuth and elevation to change the effective viewpoint of the observer.

Fusion also offers potential capabilities to support enhanced orientation, situational awareness, and information extraction capabilities. Disparate data sources, such as SAR imagery and DTM elevations, may be combined (overlaid) so as to support a 2 ½–D display of the SAR images.

Objective and Approach

The objective of this study was to perform an operational assessment of the relative utility of 2–D and 2 ½–D displays of SAR imagery. In the 2–D case, the SAR images were viewed conventionally. In the 2 ½–D case, the SAR image was overlaid on the corresponding DTM model. Subject matter experts (SMEs), military IAs assigned to the Israel Air Force (IAF), the Intelligence Command, or the Ground Corps Command, performed orientation and information extraction tasks using both display formats. The study was conducted at the facilities of Synergy Integration, Ltd., Tel Aviv, the contractor to the IAF's Human Factors Engineering Branch (IAF HFEB), with the support of PAMAM Human Factors Engineering, Ltd., the contractor supporting the Air Force Research Laboratory (AFRL), during the period 19 August through 17 September 1998.

METHOD

Imagery

The SAR imagery used in this experiment was acquired by a developmental sensor flown on the Israel Aircraft Industry's Boeing 737 multi-mode radar testbed aircraft. The imagery had a nominal resolution of 1.2 m. The imagery, in detected form, had a nominal dynamic range of 8 bits (or 256 gray levels). All imagery was acquired at high grazing angles (approximately 45 degrees).

Three imagery swaths were provided by the Israeli Ministry of Defense. The first included coverage of the Armored Command Museum at Latrun. The second included the area of Rosh Ha'ayin and the third included coverage of Ben Gurion International Airport. Thirty-eight stimulus images were extracted from the Latrun and Rosh Ha'ayin swaths. Six images, used only for familiarization with the task and practice with the apparatus, were extracted from the Ben Gurion coverage.

The Rosh Ha'ayin and the Latrun swaths differed in scale. In the Rosh Ha'ayin swath, each centimeter of the displayed image represented approximately 60 meters on the ground. In the Latrun swath, each centimeter of the image represented approximately 92 meters on the ground. As a result, the width of Rosh Ha'ayin swath was approximately 1 km by 1 km and that of the Latrun swath, approximately 1.5 km by 1.5 km. The size of each of the images was 700 by 700 pixels.

Selection of "Targets"

The experimental design was constrained, to some extent, by the coverage of the available imagery. Since the objective of the experiment was to investigate the effect, on both orientation and situational awareness, of SAR imagery overlaid on a three-dimensional terrain elevation database and viewed in a 2 ½–D display, no buildings were included as targets. A senior and highly experienced IAF IA first determined the coverage of the SAR imagery against a 1:50,000 scale survey map. Features (such as river bends, confluences/divergences of streams, the intersections of dirt roads, etc.) were selected from the map information for use as designation "targets," and their Universal Transverse Mercator (UTM) coordinates were read and recorded. These same features were then located within the SAR images, and the corresponding pixel location was read and recorded. This process was repeated until all 38 stimulus targets and the six practice targets had been selected. The target location coordinates were maintained as the "school solution" for scoring the accuracy of the designation portion of the task. The imagery was then divided into 22 matched pairs (one half of each pair to be presented in 2 ½–D and the other half in 2D). The pairings were made on the basis of containing similar targets within similar backgrounds.

Overlay of SAR Imagery onto DTM Data

Commercial off-the-shelf software (MultiGen II Pro, from MultiGen, Inc., San Jose, California) was used by Synergy Integration, Ltd., Tel Aviv, to convert the SAR pixel coordinates into UTM coordinates—the reference system used for the DTM data. Multiple control points were selected from each of the SAR images and their geographic reference locations were carefully determined from the map. A transformation program using these control points was used to convert every pixel location into its corresponding UTM coordinates. One SAR image from each matched pairing was then overlaid onto the corresponding DTM elevation data (using the same software package). The product of this procedure was a 2 ½–D representation of the area (as compared to the 2–D representation of the original SAR imagery).

No additional exaggeration to the elevation data was introduced. Thus, the displayed image of the overlaid SAR and DTM depicted ground distances (z and y) and heights (z) in the ratios of 1:1:1.

Experimental Apparatus

All data collection was performed at the facilities of Synergy Integration, Ltd. The images were displayed and designation coordinates and response times were recorded using a Silicon Graphics, Inc. (SGI) ONYX graphics workstation equipped with an Infinite Reality Engine multi-processor. The workstation was also equipped with a SGI model CM2187ME 533 mm (21 inch) diagonal color monitor. The display resolution (full screen) was 1280 by 1024 pixels. The brightness and contrast controls of the display were set by the Experimenter. The apparatus was located in a laboratory setting and was used to support both stimulus preparation and data collection. All stimulus imagery was displayed using commercial off-the-shelf software (the VEGA general visualization environment from Paradigm Simulations, Inc., Dallas, Texas). The displayed image (700 by 700 pixels) was approximately 200 by 200 mm (8 by 8 inches) on the monitor.

Subject Matter Experts

Five enlisted IAs from the Israel Defense Force Ground Corps Command's Imagery Analysis Unit, three IAs from the IAF, and two weapon systems officers (WSOs) of the IAF served as subject matter experts (SMEs). All were male. They ranged in age from 19 to 25 years. Their experience in tactical imagery exploitation ranged between 6 months and 6 ½ years. Four of the IAs and both WSOs had some experience with SAR imagery; all of them had experience in the exploitation of electro-optical (photography and television) sensor collections, and all had previous experience in performing softcopy imagery exploitation. None of the SMEs had previous experience in exploiting high resolution SAR imagery (as was used in the present study).

All SMEs had 6/6 (20/20) vision, uncorrected or corrected, and all had received formal military training in imagery analysis during a three-month duration service school.

The SME Task

Figure 1 depicts the sequence of events which composed the experimental task. Upon arrival at the laboratory facility, the SMEs were informed as to the purpose of the study and instructed regarding the conduct of the experiment. The instructions to the SMEs explicitly placed primary emphasis on the accurate performance of the designation component of the task but also emphasized the requirement to complete the task as rapidly as possible. The instructions also included the caution that the imagery was more recent than the map and might contain (extensive) differences with respect to the addition of man-made structures such as buildings and roads.

Information regarding the SME's background, training and imagery exploitation experience was elicited through a brief questionnaire which included questions regarding their formal training in the exploitation of SAR imagery and their experience in interpreting softcopy and SAR imagery. The SME was then seated at the graphics workstation.

At the beginning of the task, each SME was shown an extract from a 1:50,000 scale, color, topographic survey map of Israel. The map, oriented north-up and covering approximately 2 km by 2 km in area, had been annotated to depict the coverage of a SAR image at a different orientation and included a red dot marking the location of a target. This map allowed the SME to understand the relative differences in coverage between succeeding map extracts and their corresponding SAR images. They were then instructed in the use of the apparatus for the imagery orientation and target designation portions of the task. The practice images were used to allow the SMEs to gain proficiency in the use of the equipment, the orientation and target designation components of the experimental task, and the nature of the SA questions. Any remaining questions that the SMEs might have had regarding the task were answered by the Experimenter at this time. When the SMEs reported that they were confident in the execution of the task, the data collection trials were initiated.

At the beginning of each of the 38 data collection trials, a 1:1 scale extract from a 1:50,000 scale, color, topographic survey map of Israel was provided to the SME. The map extract was always oriented north-up and covered approximately 2 km by 2 km in area. The header on the map copy described the type of target to be located (e.g., dome, intersection of a dirt road and a stream, etc.), while the exact location of the specific target of interest was depicted on the map itself by a small red dot. The map extracts were mounted as successive pages in a flip chart-type booklet. The Experimenter initiated each trial by depressing a specific function key on the keyboard. The SME was permitted 15 seconds for map study. During this interval, the image display region was blank (showing a solid, medium luminance, light blue field). The Experimenter informed the SME whether the current trial was a 2–D or 2 ½–D display format. The SAR image

containing the target then appeared on the workstation display. The images were always presented so that the radar shadows pointed toward the bottom of the display (i.e., as if the radar were illuminating the ground from along the top edge of the display). No restriction was placed on the viewing distance between the SME and the workstation monitor.

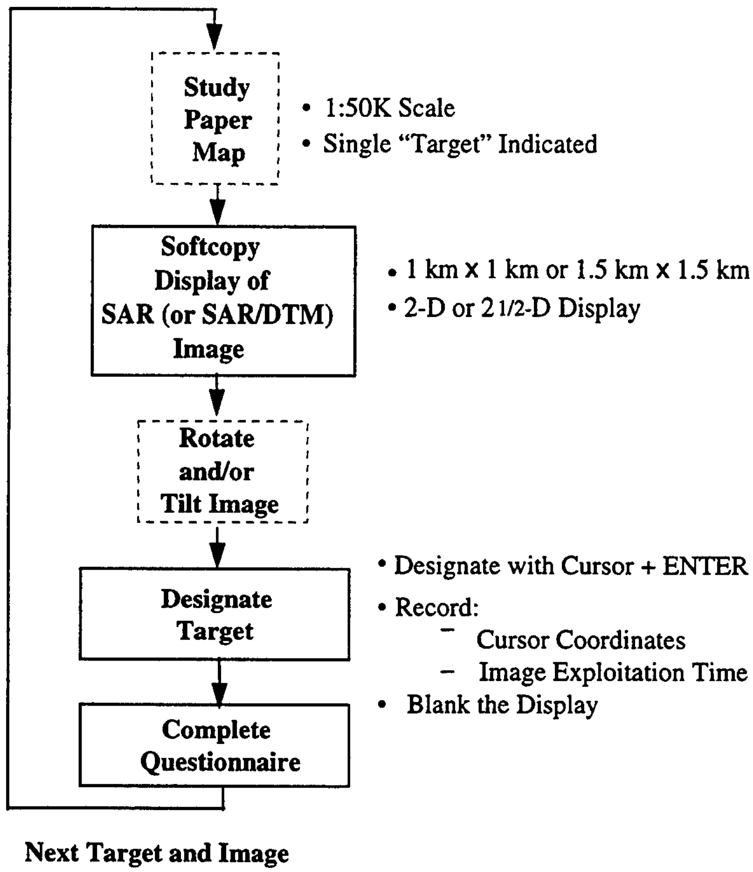

Figure 1: Flow diagram of the SME's task.

The SMEs were permitted up to 3 minutes (180 seconds) during which they were required to orient themselves to the SAR image in the context provided by the map information (which was available throughout the trial), to locate the pre-briefed target, and to designate the target. At the completion of the tasks, the display automatically went blank and performance time was recorded. If the SME did not respond within 180 seconds, the display went blank and the trial was recorded as having "timed out." During this 3-minute period the SMEs could use the left and right arrow keys on the workstation keyboard to rotate the image through a full 360 degrees of azimuth. The up and down arrow keys "tipped" the image through 90 degrees of "elevation." Rotation in both azimuth and elevation were continuous and could be applied in any combination.

For each SME, half the stimulus images were presented in overlay on the DTM elevation data. In these cases, rotation of the displayed image produced a 2 ½–D view.

In the other half of the trials, a 2–D view was presented. The arrow keys could still be used for tip and rotation, but no elevation data were overlaid on the SAR images. The mouse was used to drive an "arrow" cursor on the display to any point on the image. When the SME had located the target, the ENTER key on the keyboard was used to record the target location into the data file for that trial. (The use of the ENTER key was preferred to the use of a mouse key in order to prevent involuntary motion of the mouse cursor during designation.)

Upon designation, the display was blanked, and the location of the designated point was automatically recorded, along with the time duration between stimulus onset and the act of target designation. The SME then flipped the page in the map booklet (thus precluding any further reference to the map) and found two questions regarding the image presented during the just-completed trial. These SA questions dealt either with absolute or relative terrain height judgments or with the relative location of other objects in the SAR image. The answers to the questions were recorded manually by the Experimenter. This allowed for immediate answers to any SME requests for clarification of the SA questions.

Situational Awareness Questions

Two situational awareness (SA) questions were developed by the Experimenters for each target image. These questions dealt with absolute or relative terrain height judgments (e.g., which bank of a stream was higher; which slope of a dome was steepest?) with the direction of objects (e.g., what was the direction of the stream?) or with the relative location of objects in the SAR image (e.g., in which direction from the stream bend were two large buildings?). Each of the SA questions was presented in multiple choice form. Three possible answers to each question were presented, and the SME had to select the correct one. No time limit was imposed in answering these questions.

Once the SA questions had been answered, the trial was completed. The SME then indicated readiness to proceed with the next trial. This sequence was repeated until all 38 images had been presented to the SME. The SMEs were given a short break after each group of 8 to 12 trials (while the Experimenter loaded a different SAR swath).

Rating Scale Questions

After all 38 stimulus images had been presented, the SME was asked to complete a series of rating scale questions regarding overall impressions of the task and of the two different display formats. Each scale consisted of seven points with semantic anchors at each endpoint (as shown in Figure 2).

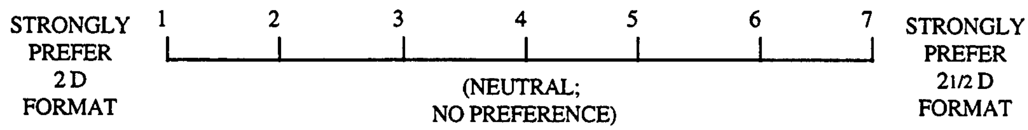

Figure 2: Rating scale with semantic anchors.

A rating of "1" always meant that the 2 ½–D display greatly degraded the SME's ability to perform the referenced function, while a rating of "7" always meant that the 2 ½–D display greatly enhanced that ability. The first group of questions dealt with comparisons between the 2–D and 2 ½–D display formats with respect to performing general orientation, assessing the structure of the terrain, assessing differences in terrain heights, and assessing terrain slopes. The next scale required the SME to rate the utility of the 2 ½–D display format in supporting general imagery interpretation tasks. Another set of questions related to SA. The SME was asked about the differences between the 2-D and 2 ½–D display formats in supporting giving answers to the SA questions. The SMEs were also asked to comment on whether they relied primarily on the map extract or on the SAR imagery in answering these questions. They were also requested to comment on the relevance of the SA questions to their current military duties. Provision was also made for the SMEs to record any overall impressions or comments regarding the entire experiment. The completed questionnaires for all SMEs are presented in Appendix A.

Upon completion of the rating scales, data collection was ended, and the SME was thanked for participation in the experiment. Each SME participated for approximately 2 hours, including instruction, practice, data collection, and completion of the questionnaire.

Experimental Design

A mixed, within-subject experimental design was employed. Half of the SMEs were presented with one half of the matched SAR image pairs overlaid onto the DTM data; the other half of the SMEs were presented with the alternate half of the image pairs presented in overlay. Half of the SMEs were presented with the experimental imagery in the reverse order from that presented to the other SMEs. This counterbalance was to protect against learning effects. Thus, there were four unique combinations of imagery presentation: order of presentation and DTM or non-DTM underlay (the independent variable of interest).

ANALYSIS AND RESULTS

Accuracy Computation

The distance between the actual location of each target and the point designated by each subject during each trial was calculated as follows. Targets were divided into two categories, targets with an accurate location (e.g., road junction, stream intersection) and targets whose exact geolocation was less certain (e.g., dome).

For each target category, a different scoring system was used.

1. For targets with an accurate location:
   - A designation distance of less than 0.8 cm on the screen was considered accurate. This translates to a distance of less than 48 m in the Rosh Ha'ayin swath, and of less than 73.6 m in the Latrun swath.
   - A designation distance of 0.8-1.6 cm was considered a partially accurate designation. This translates to a distance of 48-96 m in the Rosh Ha'ayin swath, and of 73.6-147.2 m in the Latrun swath.
   - A designation distance larger than 1.6 cm was considered an error. This translates to a distance of more than 96 m in Rosh Ha'ayin and more than 147.2 m in Latrun.

2. For targets of less certain location:
   - A designation distance of less than 1.6 cm on the screen was considered accurate (less than 96 m in the Rosh Ha'ayin swath and less than 147.2 m in the Latrun swath).
   - A designation distance of 1.6-4.8 cm was considered a partially accurate designation (96-288 m in Rosh Ha'ayin and 147.2-441.6 m in Latrun).
   - A designation distance larger than 4.8 cm was considered an error (more than 288 m in Rosh Ha'ayin and more than 441.6 m in Latrun).

A score of 2 was assigned to each accurate designation, a score of 1 to each partially accurate designation, and a score of 0 to errors.

The differences between ground distances which represent a certain level of accuracy in the Latrun and the Rosh Ha'ayin swaths are due to differences in scale between the two. It was decided to base error computation on designation distances in the image rather than on ground distances, because they provide a better representation of subjective accuracy.

Target Designation Accuracy Results

Individual Scores

Accuracy scores for each SME and each image are presented in Appendix B.

Overall Accuracy Scores

The mean accuracy score for the 2–D display was 1.33 and for the 2 ½–D display, 1.39. This difference is not statistically significant.

Analysis of the accuracy scores by swaths (Latrun or Rosh Ha'ayin) did not yield any significant main effect or interaction.

Selected Targets Accuracy Scores

It was hypothesized (based on subjects' comments—see Appendix A) that while overlaid SAR-DTM images may not be particularly advantageous in flat areas or in areas that contain salient human-made features, they may provide an "edge" in areas which are mountainous and without salient features. To test this hypothesis, a subset of images was selected which contains mountainous areas, without salient human-made features. The selected targets included 12 images from the Latrun swath and 8 images from the Rosh Ha'ayin swath.

For the selected images, the average accuracy scores were 1.13 for 2–D and 1.20 for the 2 ½–D. This difference is not statistically significant.

Analysis of the accuracy scores of the selected images by swaths (Latrun or Rosh Ha'ayin) did not yield any significant main effect or interaction.

It may be seen that the scores for the selected targets are lower than the scores for the whole set, indicating that these sections tended to be more difficult than the average.

Difficulty Levels

In order to rule out possible floor and ceiling effects, accuracy scores were computed without the easiest and without the most difficult targets.

The targets were divided into three difficulty levels, according to their average distance score.

- Difficult: 0-0.8 (6 targets).
- Medium: 0.9-1.8 (25 targets).
- Easy: 1.9-2 (7 targets).

The six "difficult" and the seven "easy" targets were eliminated and only the medium difficulty level targets were analyzed. The difference between the 2–D and 2 ½-D average scores was somewhat larger than for the whole set (1.33 and 1.46, accordingly). However, this difference failed to reach statistical significance.

Learning Effects

Based on subjects' comments and on the fact that 2 ½–D displays were new to all subjects, it was hypothesized that 2 ½–D image responses may have been affected by learning during the experiment more than those for the 2–D images.

Figure 3 represents average performance for each of the 38 trials. (Note that because of the counterbalancing procedures, the accuracy score of each trial is based on more than one image.) It can be seen that, while the first 2 ½–D trials tend to be less accurate than the first 2–D trials, the last trials tend to be more accurate. The interaction between trial and accuracy did not reach statistical significance.

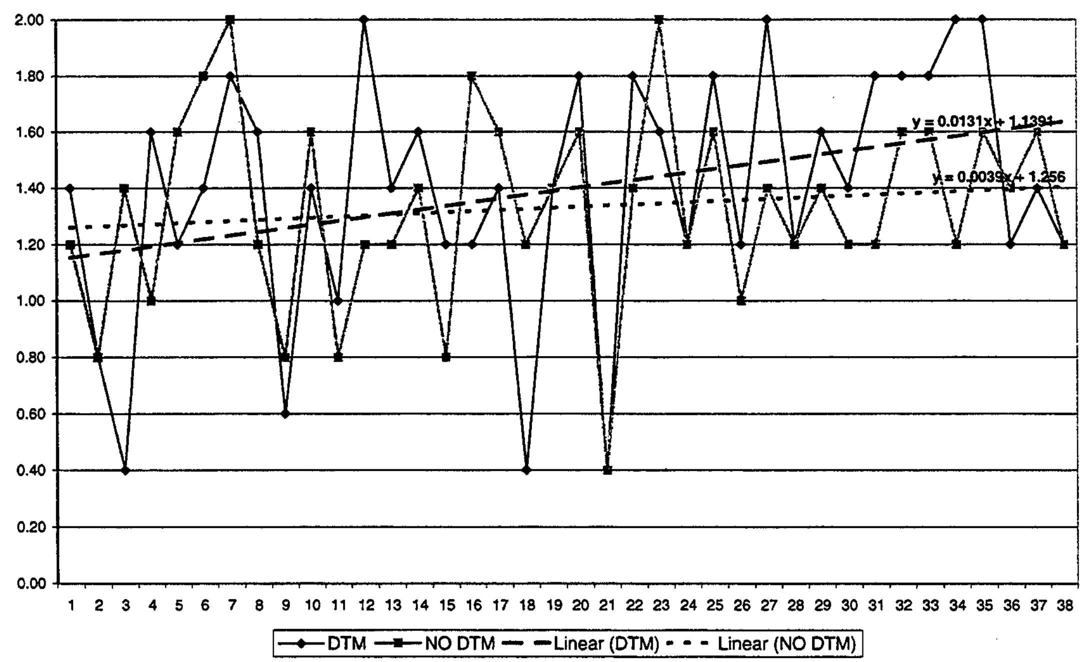

Figure 3: Accuracy scores by order of trials.

Individual Differences

The mean performance of some of the SMEs seems to have benefited from the overlay of the SAR-DTM, while the mean performance of others was degraded. An overall picture of individual performance can be seen in Appendix B. Table 1 presents general IA experience, SAR experience, accuracy scores with 2–D and 2 ½–D images, and the difference scores. The general trend seems to be that SMEs with little or no SAR

experience benefited more from the SAR-DTM overlay than SMEs with SAR experience. It may also be noted that, on the average, the two WSOs performed more accurately than all IAs and that the best IA was also the most experienced one.

Table 1. Experience Levels and Accuracy Scores of the SMEs

SME	General experience (years)	SAR experience (years)	Accuracy score 2D	Accuracy score 2 ½–D	Difference
4 – IA	0.5	0	0.89	1.00	0.11
3 – IA	1.5	0	1.00	1.37	0.37
2 – IA	2.5	0	0.95	1.39	0.44
5 – IA	2.5	0	1.21	1.42	0.21
1 – IA	1	1	1.00	1.32	0.32
8 – IA	1.5	1	1.47	1.26	-0.21
9 – IA	2	1.5	1.42	1.37	-0.05
6 –WSO	WSO	2	2.00	1.89	-0.11
10 –WSO	WSO	3.5	1.63	1.53	-0.11
7 – IA	6.5	6.5	1.74	1.37	-0.37

Target Designation—Speed

The time of target designation was recorded for each target. If the subject failed to respond after 180 seconds, the display automatically went blank and a "timeout" was recorded. Only 13 timeouts were recorded for the total of 380 trials by the 10 SMEs. This low timeout rate suggests that the 180 seconds allowed for the orientation and designation components of the imagery exploitation task was appropriate to the complexity of the task.

- Four out of the 13 timeouts were associated with a single image that was particularly hard.
- More than half of the timeouts (eight) were produced by 2 of the 10 SMEs, perhaps indicating lack of experience or excessive emphasis on accuracy.

Designation time tended to be longer for overlaid SAR-DTM images. The mean response time for the 2–D images was 51.9 seconds and for the 2 ½–D, 60.6 seconds. This difference is statistically significant, $F(1)=24.71$, $p=0.0008$.

Designation times for the Latrun swath (51.79) were significantly shorter than for the Rosh Ha'ayin swath (60.68), $F(1)=22.5$, $p=0.0011$. The shorter response times in the Latrun swath may be due to the higher availability of salient human-made features in the images of the Latrun area.

Situational Awareness

SA Scores

Each trial was followed by two SA questions. A score of 1 was assigned to each correct answer, and 0, to wrong answers. SA scores were computed for trials with correct and partially correct target designations only. The final SA scores were computed as the sum of points for each trial.

Overall SA Scores

The mean SA score for the 2–D images was 1.08, and for the 2 ½–D images, 1.04. This difference is not significant.

Selected SA Questions

Based on SMEs comments (Appendix A), it was hypothesized that the overlaid SAR-DTM may affect only features that are related to height (e.g., slopes, height differences) and not other features (e.g., direction of roads). Therefore, questions regarding height differences were analyzed separately. However, this treatment did not produce significant differences between the 2–D and the 2 ½–D images.

SA by Swath

No significant differences were found between the SA scores of the Latrun and the Rosh Ha'ayin swaths.

Types of SMEs

The SMEs who participated in the study came from of two groups: eight image analysts (IAF and ground forces) and two WSOs (IAF aircrew). A statistical analysis was performed for all 10 SMEs, and another was performed for the 8 IAs only. This treatment did not produce significant differences between the 2–D and the 2 ½–D designation accuracy scores or SA ratings.

Rating Scales

The first four questions on the rating scale dealt with the strength of the SMEs preference for either the 2 ½–D or the 2–D SAR display format in the context of supporting the IA's ability to orient to the terrain scene. The first question addressed general orientation, the second addressed the assessment of landforms/terrain structure, the third, understanding of terrain height differences, while the fourth explored understanding of differences in terrain slopes. As depicted in Figure 4, the SMEs as a group expressed a marked preference for the 2 ½–D display format. (In Figure 4, a mean rating of 4.0 reflects no preference between the two formats.)

The fifth rating scale required the SMEs to express their preference in the context of the utility of the display format to support imagery interpretation in general. A preference for the 2 ½–D format was found.

The sixth rating scale explored the two display formats in the context of SA. Again, a preference for the 2 ½–D was elicited.

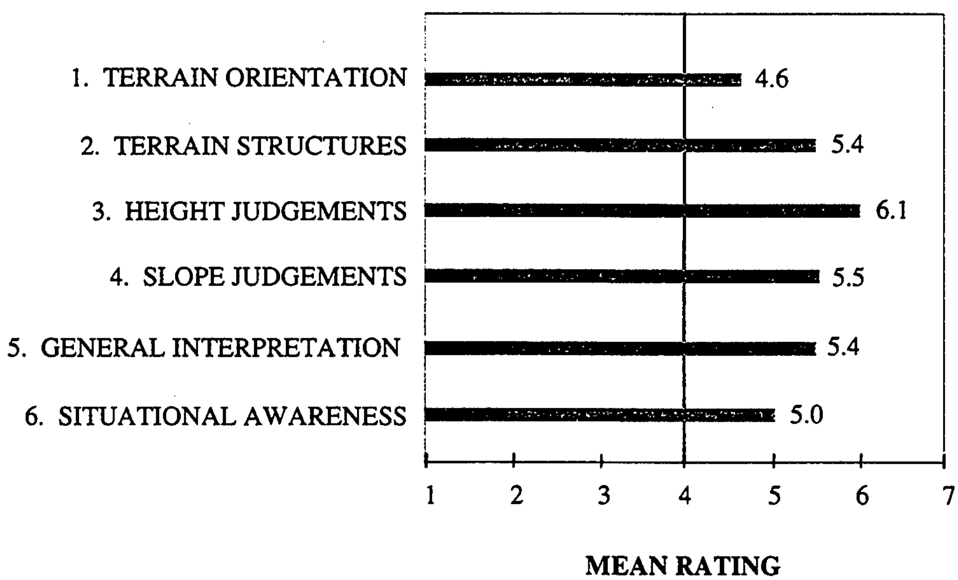

Figure 4: Mean ratings for responses to six questions.

All ratings were significantly higher than the mean score (4.0). Table 2 presents the statistical summary for 10 SMEs.

Table 2. Mean Ratings and T Scores for the Six Rating Scale Questions

Question	Mean rating	T score	Probability
1	4.6	2.64	0.0331
2	5.4	4.24	0.0038
3	6.1	13.74	0.0001
4	5.5	3.53	0.0096
5	5.4	5.22	0.0012
6	5.0	2.55	0.0379

Observations

Before discussing the implications of the results from the formal measures used in the study, some observations on the part of the Experimenters, made during the data collection runs, may give the reader insight into the study.

- None of the SMEs had any apparent difficulty in employing the display/controls mechanization (arrow keys, mouse, enter key) used in this study.
- Although none of the SMEs had any experience in the exploitation of high resolution SAR, they were all able to complete the target designation task without any reported difficulty.
- All IAs had received training in landform and traversability analysis as part of their IA school curriculum.
- Some SMEs indicated that the effective usage of 2 ½–D images may require additional practice, and perhaps, even formal training.
- Wide-ranging, individual differences were observed with regard to the strategies employed by the SMEs in viewing the SAR display. Some SMEs physically rotated the paper map to match the orientation of the SAR (regardless of whether DTM data were available). This kept the radar shadows pointing toward the bottom of the display—a technique that IAs are taught to employ to avoid a "false" reversal in apparent elevation / depression of the scene. Others appeared to first rotate the SAR display (again regardless of the format) and then to quickly tilt the displayed image, apparently to gain an appreciation for terrain relief.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

High resolution SAR imagery, collected at high grazing angles, does not appear to present any of the difficulties conventionally associated with low and medium resolution non-literal imagery—at least in the context of the present salient landform designation and terrain-based SA tasks. This also suggests that only minimal impact to the training support system may be encountered as these systems become operational.

Designation scores with the overlaid SAR-DTM imagery (2 ½–D) produced slightly higher accuracy scores than with SAR alone (2–D). However, these differences were small and did not reach statistical significance. The general pattern of results did not change when only selected targets, which contained mountainous areas and no salient human-made features, were analyzed. The elimination of the most difficult and the easiest trials from the statistical analysis increased the differences between the 2–D and the 2 ½-D scores, but this difference, too, failed to reach statistical significance. Several factors may have affected the potential effects of an overlaid SAR-DTM imagery on the accuracy of target recognition:

- The sets of SAR swaths used in the study were rather limited in size and included only small areas, which were both mountainous and free of salient human made objects. Hence, the number of sections in which the SAR-DTM overlay could provide significant advantages was rather small and the variety was very limited.

- Because of the limited width of each swath and the small variety of useful sections the size of the area displayed during each trial was significantly smaller than the size of area which IAs use in their regular routine. This made the use of terrain features more difficult than usual.

- The use of the overlaid SAR-DTM seems to require some training. This was indicated by the results, which show a larger improvement in SAR-DTM performance than in SAR alone, and was pointed out by some of the SMEs as well.

Response times were approximately 17 percent longer for the 2 ½–D trials than for the 2–D trials. This is not surprising, given that the 2 ½–D images contain more information. Additionally, during the 2 ½–D trials subjects made more extensive use of the tilt option, which provided them with different views of the terrain, whereas tilting the 2–D images was possible but did not provide any extra information.

Situation awareness, as measured by the questions at the end of each trial, did not benefit from the overlay of SAR-DTM. Two reasons may have affected the results. First, the answers to the SA questions could be extracted from the maps, as well as from the

SAR images. At the end of the experiment, SMEs were asked about the extent to which their SA answers were based on the SAR imagery as compared with the map (see Appendix A). Most SMEs reported that the maps were an equal or a dominant source of SA information. Obviously, the use of the map obscures SAR imagery effects. Secondly, although all IAs considered the SA questions as relevant to their jobs, they also indicated that the level of detail required tended to be higher than is usually required on the real "object recognition" job (e.g., comparing the slopes of two adjacent domes). Several SMEs indicated that this level of detail would be more relevant for determining traversability. Hence, some of the time SA questions were perceived as an additional, secondary task rather than as an integral part of the main target acquisition task.

Individual performance differences were quite large and seem to be related to the level of experience. Interestingly, the more experienced SAR users seem to have benefited less from the SAR-DTM overlay than the inexperienced subjects. However, these findings were not significant and require further investigation.

In their subjective ratings at the end of the experiment, SMEs expressed their faith in the 2 ½–D imagery's potential as an aid for image analysis—to improve SA, enhance general orientation, increase understanding the structure of terrain and facilitate perceiving height and slope differences. (See Appendix A for detailed answers.)

Recommendations

- Future studies should include exploration of the 2 ½–D SAR and other sensor display formats to support IA confidence in performing SA and information extraction tasks. (This recommendation is based on observation of the SMEs' strategies in carrying out the tasks.)

- The use of a DTM underlay should be studied in conjunction with various types of sensor imagery under conditions where sensor imagery may disappear or fade out (e.g., passing through a cloud, degraded conditions for thermal imagery). It is hypothesized that under these conditions, the DTM may serve as an anchor, prevent loss of orientation, and thus, enhance orientation and object recognition performance.

- SME training and individual differences have played an important role in the present study. These issues require further investigation.

APPENDIX A

QUESTIONNAIRES

(Translated from the Original Hebrew)

1. Did you prefer either of the SAR display formats for use in performing the terrain interpretation subtasks of:

a. General orientation between the map and the image?

s----X----s

STRONGLY PREFER 2D FORMAT	1	2	3	4 (NEUTRAL; NO PREFERENCE)	5	6	7	STRONGLY PREFER 21/2 D FORMAT

(s = 1 standard deviation; X = mean of group rating)

b. Understanding the general structure of the terrain?

s--------X--------s

STRONGLY PREFER 2D FORMAT	1	2	3	4 (NEUTRAL; NO PREFERENCE)	5	6	7	STRONGLY PREFER 21/2 D FORMAT

c. Understanding differences in terrain heights?

s------X------s

STRONGLY PREFER 2D FORMAT	1	2	3	4 (NEUTRAL; NO PREFERENCE)	5	6	7	STRONGLY PREFER 21/2 D FORMAT

d. Understanding differences in terrain slopes?

s-----------X-----------s

STRONGLY PREFER 2D FORMAT	1	2	3	4 (NEUTRAL; NO PREFERENCE)	5	6	7	STRONGLY PREFER 21/2 D FORMAT

SME comments regarding interpretation of terrain:

SME 1. ------
SME 2. 2 ½–D was helpful only when there were height differences.
SME 3. No difference in flat areas.
SME 4. ------
SME 5. ------
SME 6. ------
SME 7. 2 ½–D may help in areas with height differences and without other salient cues.
SME 8. ------
SME 9. Orientation is normally based on salient features and not on terrain structure; my attempt to use the 2 ½–D did not succeed.
SME 10. One needs to get acquainted with the 2 ½–D format.

2. Which SAR display format would be of greatest utility in performing general imagery analysis tasks?

					s-------X-------s			
STRONGLY PREFER 2D FORMAT	1	2	3	4	5	6	7	STRONGLY PREFER 21/2 D FORMAT
				(NEUTRAL; NO PREFERENCE)				

SME comments regarding utility of the SAR display formats to general imagery analysis tasks:

SME 1. Presently irrelevant; may be of help for understanding traversability and detecting obstacles.
SME 2. ------
SME 3. Useful for orientation.
SME 4. Useful in areas without man-made cues.
SME 5. May be of help for detecting traversability problems.
SME 6. (WSO) height and slope differences are not very important for my work.
SME 7. May improve the general understanding of terrain structure, and in particular, traversability.
SME 8. ------
SME 9. Get a better idea about terrain structure.
SME 10. (WSO) May support orientation, especially where there are height differences

3. Were the tasks used in this experiment relevant to your normal duties as an imagery analyst?

SME comments regarding the relevance of the experimental tasks to normal duties:

SME 1. Not relevant for SAR interpretation, in which there is no strong emphasis on the terrain.

SME 2. Yes, for the process of initial orientation.
SME 3. May help to extract target accurate coordinates.
SME 4. The usage of map and SAR was relevant.
SME 5. The parallel use of the map and the SAR was relevant.
SME 6. As a WSO, it may help orientation, but is more important for Ias.
SME 7. Yes, the orientation part.
SME 8. May help in defining traversability and obstacles.
SME 9. Yes, orienting between a map and a SAR image.
SME 10. (WSO, not AI) – may support the orientation process.

4. Was there a difference between the two the SAR display formats for use in responding to the situational awareness (SA) questions asked after each trial?

s------------X------------s

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE
				(NEUTRAL; NO PREFERENCE)				

SME comments regarding responding to SA questions:

SME 1. DTM is not necessary when there are 2–D salient cues.
SME 2. ------
SME 3. ------
SME 4. ------
SME 5. The conclusions from the map were sometimes quantitatively different than those drawn from the SAR; this posed a decision problem.
SME 6. Yes, the orientation and location of specific areas on the ground.
SME 7. 2 ½[–D] helps when there are height differences.
SME 8. Directions, with the map; for heights, the SAR-DTM has an absolute advantage.
SME 9. ------
SME 10. Used the 2 ½[–D] for difficult 3–D areas.

5. Were your responses to the SA questions based (primarily) on the SAR image (either display format) or on the paper map?

SME responses regarding use of SAR imagery versus paper map in responding to SA questions:

SME 1. Both.
SME 2. Both.
SME 3. Extracted directions from the map, altitude and slopes from the SAR.
SME 4. Map
SME 5. Map, except for questions which had no answer on the map.

SME 6. Map.
SME 7. Both, the SAR-DTM provides a more accurate view of the terrain.
SME 8. Map.
SME 9. Both.
SME 10. Primarily the map.

6. Were the terrain features ("targets") that were included in the target designation and SA tasks relevant to your duties as an imagery analyst?

SME comments regarding relevance of terrain features:

SME 1. Sometimes (e.g., intersections of dirt roads).
SME 2. Not really.
SME 3. May be relevant for terrain interpretation but not for tactical interpretation.
SME 4. ------
SME 5. Relevant only for traversability research.
SME 6. Not relevant for a WSO.
SME 7. features are relevant for orientation.
SME 8. Prefers 2–D because he is used to it.
SME 9. For softcopy IA the orientation part will be secondary because of automatic system support.
SME 10. Not really; these details are relevant for orientation, but not for interpretation.

7. General comments:

SME 1. ------
SME 2. ------
SME 3. ------
SME 4. ------
SME 5. In general, this looks very promising.
SME 6. ------
SME 7. ------
SME 8. 2 ½–D may help in locating obstacles and landing areas.
SME 9. ------
SME 10. The requirement to rotate the SAR image north-up, (in order to prepare for SA questions) is an obstacle, because we usually view them from the direction from which they were taken.

APPENDIX B

The following table presents the accuracy scores for all subjects in all trials.

"Swath": is either Latrun or Rosh Ha'ayin.

"Target": is the serial number of the SAR and map section which was used for one trial.

"Target type": 0 = targets with an accurate location; 1 = targets that were spread on a larger area.

"DTM": 0 = SAR only; 1 = SAR+DTM. For each target, the left side of the table presents the scores of the SMEs who performed with SAR only and the right side presents the scores of the SMEs who performed the same target with SAR+DTM—or *vice versa*.

"SME":
1 - Israeli Ground Corps Command Unit (1 – 5)
2 - Israel Air Force Imagery Analysis (7 – 9)
3 - Weapon systems officers (6, 10)

"0" score, in **boldface type**, indicates "timeout" (no target designation response during 180 seconds); 13 timeouts were recorded during the whole study.

"x" – indicates missing data

Table B–1. Accuracy Scores for all Subjects in all Trials

SME 10[3]	SME 9[2]	SME 7[2]	SME 4[1]	SME 2[1]	DTM	SME 8[2]	SME 6[3]	SME 5[1]	SME 3[1]	SME 1[1]	DTM	Target type	Target	Swath
2	2	2	2	0	1	2	2	2	2	2	0	0	1	Latrun
2	2	2	0	0	0	2	2	2	2	2	1	1	2	
1	2	0	2	2	1	2	2	2	0	2	0	1	3	
1	2	2	0	0	0	0	2	2	1	1	1	1	4	
2	2	2	0	0	1	2	2	2	2	0	0	0	5	
2	0	2	0	0	0	0	2	0	0	0	1	0	6	
0	2	0	1	0	1	0	2	0	0	0	0	0	7	
0	0	2	0	0	0	0	2	0	0	0	1	0	8	
2	0	0	0	2	1	2	2	2	0	2	0	0	9	
2	1	2	1	1	0	1	2	2	1	2	1	0	10	
0	0	0	0	2	1	2	2	0	0	0	0	0	11	
2	2	2	2	2	0	2	2	2	2	2	1	1	12	
1	2	2	2	2	1	2	2	2	2	2	0	1	13	
2	2	2	2	2	0	2	2	2	2	2	1	1	14	
2	2	2	2	x	1	2	2	1	2	0	0	1	15	
2	2	2	2	0	0	2	2	2	2	2	1	0	16	
2	2	2	2	2	1	2	2	2	2	2	0	1	17	
2	2	2	2	2	0	2	2	2	1	2	1	1	18	
2	2	2	0	2	1	2	2	0	0	0	0	1	19	
2	0	1	1	1	0	2	2	2	1	2	1	0	20	
2	2	2	2	2	1	2	2	2	2	1	0	0	27	R.H
2	2	2	0	0	0	2	2	2	2	2	1	0	28	
2	2	2	2	0	1	2	2	2	2	2	0	1	29	
2	2	2	2	2	0	2	2	0	2	2	1	1	30	
2	0	2	0	2	1	1	2	2	0	0	0	1	31	
2	2	2	2	2	0	2	2	2	2	2	1	0	32	
0	2	2	2	0	1	2	2	0	0	0	0	1	33	
1	1	0	2	1	0	0	2	1	0	0	1	1	34	
2	0	2	0	2	1	2	2	1	2	2	0	0	35	
1	2	1	0	2	0	0	2	0	2	0	1	0	36	
1	0	0	0	2	1	0	2	0	0	2	0	0	37	
1	2	1	1	1	0	1	0	2	2	2	1	0	38	
2	2	2	2	2	1	0	2	2	2	2	0	0	39	
2	2	2	0	2	0	2	2	1	2	2	1	0	40	
2	1	1	0	1	1	0	2	0	0	0	0	1	41	
2	0	2	0	0	0	0	2	2	0	0	1	1	42	
2	1	1	0	2	1	1	2	1	1	0	0	0	43	
1	1	2	0	0	0	2	2	1	2	0	1	0	44	
1.53	1.37	1.37	1.00	1.39	Average SAR+DTM	1.26	1.89	1.42	1.37	1.32	Average SAR+DTM			
1.63	1.42	1.74	0.89	0.95	Average SAR only	1.47	2.00	1.21	1.00	1.00	Average SAR only			

GLOSSARY

2–D	two-dimensional
2 ½–D	2 ½-dimensional
AFRL	Air Force Research Laboratory (United States)
cm	centimeter
D	dimension(al)
DEA	Data Exchange Annex
DTM	digital terrain map
HFEB	Human Factors Engineering Branch (of the IAF)
IA	imagery analyst
IAF	Israel Air Force
IOF	International Opportunities Fund
J-STARS	Joint Surveillance and Target Acquisition Radar System
km	kilometer
m	meter
mm	millimeter
pixel	picture element
SA	situational awareness
SAR	synthetic aperture radar
SME	subject matter expert(s)
UTM	Universal Transverse Mercator
WSO	weapon systems officer